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DIFFERENCE IN WAVE-LENGTHS OF TITANIUM λλ 3900 AND 3913 IN ARC AND SPARK.

By Norton A. Kent and Alfred H. Avery.

Presented by J. Trowbridge October 9, 1907. Received October 9, 1907.

In June, 1905, one of the writers of the present paper published the results of a careful series of experiments dealing with the variation in the wave-length of certain lines of the spark spectra of titanium, iron, and zinc with the electrical conditions of the discharge.[1] Subsequently Keller, working under Kayser, published a paper[2] in which the suggestion was made that the apparent non-coincidences of the spark and the comparison arc lines were due to the fact that the slit was not accurately adjusted to parallelism with the grating ruling; and the statement was made that the plumb-line method of adjustment employed by the writer was of less delicacy than the spectroscopic.

The substance of Keller's explanation of the manner in which shifts could be introduced by orientation of the spectrometer slit is as follows: Given a perpendicular grating ruling, an astigmatic instrument such as the concave grating will give a perpendicular line image for every point of the line source as object. If, then, the line source or slit be at an angle (say clockwise as one faces it) with the grating ruling, each spectral line will be a composite of lines arranged as in Figure 1.

The result will be an image which is apparently rotated in the direction of the slit. If, then, on one photographic plate two exposures be made, one each of arc and spark, and the position of the adjacent tips of the images of any spectral line be measured by a comparator, any displacement desired may be introduced by a rotation of the slit.

But Keller's explanation does not apply to the method of exposure employed by the writer of the former paper — a method of triple exposure, two of the arc (the first and the third) superimposed horizontally but not wholly vertically and spanned by the spark exposure, as in Figure 2.

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[1] These Proceedings, **41**, No. 10, July, 1905.

[2] Ueber die angebliche Verschiebung der Funkenlinien. Inaugural-Dissertation Christian Keller. 1906.

It is difficult to see how non-parallelism of slit and ruling could in this case introduce a shift. Keller seems to have overlooked the fact that this triple method was employed, for no mention is made of it in his paper. However, despite the fact that it was not apparent how

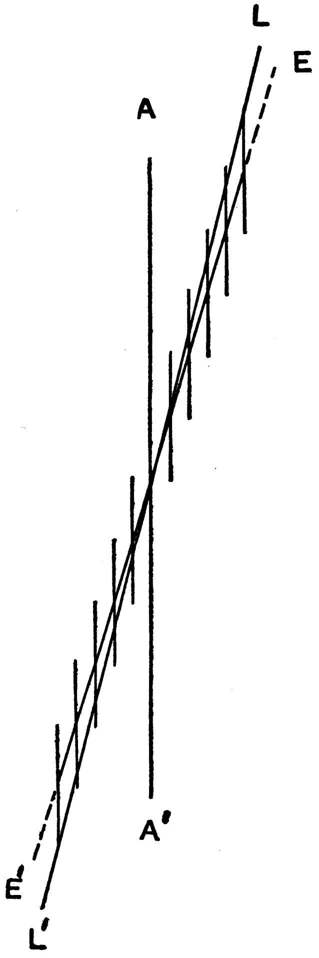

Figure 1.

AA′, direction of grating ruling; EE′, direction of slit; LL′, direction of resultant line.

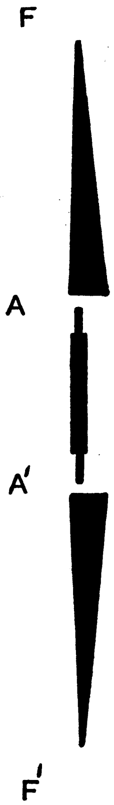

Figure 2.

AA′, two exposures of an arc line superimposed horizontally, but not vertically; FF′, spark line.

the above mentioned criticism could apply, it seemed advisable to test the matter, and the following experiments were undertaken to decide the two following questions:

(1) Is the plumb-line method of adjustment of slit and grating ruling to parallelism more or less accurate than the spectroscopic ?

(2) Will an orientation of the slit introduce a shift if the triple method of exposure be used ?

CONDITIONS OF EXPERIMENT.

The conditions under which the present work was carried on were, as far as possible, those of the previous series of experiments. By the courtesy of Professor Trowbridge and Professor Sabine every facility of the Jefferson Physical Laboratory was placed at our disposal. The grating — a 6″ Rowland concave, of 20,000 lines to the inch and 21-foot radius of curvature, an excellent instrument — was kindly loaned by Professor Trowbridge, and the mount was that belonging to the laboratory and located on the third story of the building. The beams were heavy timbers supported wholly from the walls of the building. The slit, grating holder, camera-box, rheostat, transformer, and condenser were those used in the former work. The usual precautions relative to temperature changes were taken, the whole mount being wrapped in several layers of newspaper. The vibrations of the building due to wind and heavy machinery necessitated working at times when these disturbing influences were absent. All plates not showing horizontal coincidence of the arc exposures were rejected. The current used for both arc and spark was the 110 volt, 66 cycle alternating current of the Cambridge Electric Light Company. The frequency of the current used in the previous work was 133, but as the transformer was built for 66 cycles no difficulty was experienced in this regard. The voltmeter, ammeter, and wattmeter were of Thompson form, and of ranges 0 — 65 volts; 0 — 60 amperes; and 0 — 45 hecto-watts, respectively. Thus the conditions were the same as those formerly employed in all respects but location, frequency of current, and grating.

RESULTS OBTAINED.

(1) *Relative merits of plumb-line and spectroscopic methods of adjustment.* The grating holder was fitted with two opposing screws moving in a horizontal direction and controlling the orientation of the grating. It was found by trial that by the unaided eye the parallelism of either end of the ruled space of the grating with the silk thread of a plumb-line suspended from the grating holder could be adjusted so that the

TABLE I.

Shift of spark lines λλ 3900 and 3913 to red from position of arc lines.
Metal used: Titanium Carbide, 85 per cent Ti, 15 per cent C.
Arc vertical: length 3 mm. Spark horizontal: length 9 mm.
End of spark image always used.
Capacity of condenser: 0.0226 microfarads.
Times of exposures: arc 5 + 5 seconds, spark 75 seconds.

Plate Number.	Date.	Constants of Primary Circuit.			SHIFT IN							
					λ 3900.68							
					Orientation of Slit.							
		Amperes.	Watts.	Volts.	Clockwise 360°.		Clockwise 180°.		Parallel, or 0°.		Counter clockwise 180 .	
					Kent.	Avery.	Kent.	Avery.	Kent.	Avery.	Kent.	Avery.
19	Mar. 9	. .	. .	. .	0.035	0.041	. .	. .	. .	. .	. .	. .
20	. .	. .	. .	. .	0.021	0.031	. .	. .	. .	. .	. .	. .
21	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
22	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .
23	Mar. 16	40.8	. .	15.5	. .	. .	. .	. .	. .	. .	. .	. .
26	. .	42.0	. .	15.5	. .	. .	. .	. .	. .	. .	. .	. .
32	. .	38.5	. .	19.0	. .	. .	. .	. .	0.019	0.023	. .	. .
35	. .	40.0	. .	16.5	. .	. .	0.020	0.027	. .	. .	. .	. .
36	. .	40.0	. .	16.5	. .	. .	0.012	0.022	. .	. .	. .	. .
39	. .	39.0	. .	21.0	. .	. .	. .	. .	0.027	0.028	. .	. .
40	. .	40.5	. .	17.0	. .	. .	. .	. .	0.007	0.013	. .	. .
44	Mar. 23	39.8	. .	19.0	. .	. .	. .	. .	0.029	0.030	. .	. .
45	. .	40.0	. .	19.0	. .	. .	. .	. .	0.025	0.021	. .	. .
48	. .	37.5	. .	21.5	. .	. .	. .	. .	0.018	0.018	. .	. .
49	. .	40.0	. .	18.0	. .	. .	0.015	0.020	. .	. .	. .	. .
51	. .	39.3	. .	18.0	. .	. .	0.014	0.013	. .	. .	. .	. .
52	. .	39.0	. .	19.0	0.032	0.042	. .	. .	. .	. .	. .	. .
54	. .	40.0	. .	18.8	0.016	0.023	. .	. .	. .	. .	. .	. .
58	. .	40.0	. .	19.3	. .	. .	. .	. .	. .	. .	. .	. .
63	Apr. 12	41.0	500	16.0	. .	. .	. .	. .	0.014	0.018	. .	. .
68	" 13	39.0	500	19.0	. .	. .	. .	. .	0.008	0.010	. .	. .
72	. .	40.0	490	17.5	. .	. .	. .	. .	0.023	0.023	. .	. .
74	. .	39.5	450	17.5	. .	. .	. .	. .	0.039	0.029	. .	. .
76	. .	40.0	500	22.0	. .	. .	. .	. .	. .	. .	0.025	0.019
77	. .	40.0	450	19.0	. .	. .	. .	. .	. .	. .	0.016	0.010
78	. .	40.0	450	19.0	. .	. .	. .	. .	. .	. .	0.032	0.042
82	. .	40.0	500	19.0	. .	. .	. .	. .	. .	. .	. .	. .
83	. .	41.0	450	15.0	. .	. .	. .	. .	. .	. .	0.025	0.026
85	. .	40.5	490	17.0	. .	. .	0.020	0.018	. .	. .	. .	. .
87	. .	41.0	450	16.5	. .	. .	0.020	0.021	. .	. .	. .	. .
88	. .	41.0	450	16.0	0.025	0.021	. .	. .	. .	. .	. .	. .
89	. .	40.5	450	16.0	0.018	0.026	. .	. .	. .	. .	. .	. .
101	Apr. 27	40.0	450	17.0	. .	. .	. .	. .	. .	. .	0.008	0.012
102	. .	39.0	450	19.0	. .	. .	. .	. .	. .	. .	0.011	0.009
110	. .	41.0	450	19.0	. .	. .	. .	. .	. .	. .	. .	. .
112	. .	42.5	450	15.0	. .	. .	. .	. .	. .	. .	. .	. .
114	. .	41.0	450	15.5	. .	. .	. .	. .	. .	. .	. .	. .
116	. .	41.0	550	19.0	. .	. .	. .	. .	. .	. .	0.014	0.019
117	. .	41.8	550	18.5	. .	. .	. .	. .	. .	. .	0.018	0.016
119	. .	41.5	520	19.5	. .	. .	0.015	0.018	. .	. .	. .	. .
120	. .	42.0	480	17.5	. .	. .	0.013	0.022	. .	. .	. .	. .
122	. .	41.3	500	19.0	0.014	0.014	. .	. .	. .	. .	. .	. .
123	. .	41.3	500	17.0	0.013	0.012	. .	. .	. .	. .	. .	. .
124	. .	41.5	500	17.0	0.011	0.010	. .	. .	. .	. .	. .	. .
Mean					0.021	0.024	0.016	0.020	0.021	0.021	0.019	0.019

Means of means at all orientations	λ 3900.68	λ 3913.58
Kent	0.018	0.017
Avery	0.020	0.019

TABLE I — *continued.*

Plates: Seed "Gilt Edge," No. 27.
Developer: Metol, adurol, hydrochinon.
Second order spectrum.
Width of slit: 0.025 to 0.050 mm.; length: 5 mm.
Length of grating lines: 14 mm.

TENTH-METRES.

		λ 3913.58.									
		Orientation of Slit.									
Counter clockwise 360°.		Clockwise 360°.		Clockwise 180 .		Parallel, or 0°.		Counter clockwise 180°.		Counter clockwise 360°.	
Kent.	Avery.	Kent.	Avery.	Kent.	Avery.	Kent.	Avery.	Kent.	Avery.	Kent.	Avery.
. .	. .	0.030	0.035	. .	. .	. .	. .	. .	. .	. .	. .
. .	. .	0.018	0.028	. .	. .	. .	. .	. .	. .	. .	. .
0.012	0.012	. .	. .	. .	. .	. .	. .	. .	. .	0.014	0 013
0.029	0.034	. .	. .	. .	. .	. .	. .	. .	. .	0.027	0.040
0 010	0.023	. .	. .	. .	. .	. .	. .	. .	. .	0.011	0.013
0.006	0.020	. .	. .	. .	. .	. .	. .	. .	. .	0.008	0.016
. .	. .	. .	. .	. .	. .	0.015	0.017	. .	. .	. .	. .
. .	. .	. .	. .	0.026	0.022	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	0.010	0.019	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0.023	0.024	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0.004	0.012	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0 029	0 033	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0.021	0.029	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0.014	0.017	. .	. .	. .	. .
. .	. .	. .	. .	0.018	0.017	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	0.015	0.015	. .	. .	. .	. .	. .	. .
. .	. .	0.031	0.026	. .	. .	. .	. .	. .	. .	. .	. .
. .	. .	0.016	0.020	. .	. .	. .	. .	. .	. .	. .	. .
0.012	0.016	. .	. .	. .	. .	. .	. .	. .	. .	0.015	0.015
. .	. .	. .	. .	. .	. .	0.016	0.017	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0 005	0.005	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0.023	0.025	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	0.042	0.034	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	. .	. .	0.024	0 029	. .	. .
. .	. .	. .	. .	. .	. .	. .	. .	0.016	0.008	. .	. .
. .	. .	. .	. .	. .	. .	. .	. .	0.032	0.027	. .	. .
0.028	0.023	. .	. .	. .	. .	. .	. .	. .	. .	0.024	0.022
. .	. .	. .	. .	. .	. .	. .	. .	0.020	0.018	. .	. .
. .	. .	. .	. .	0.019	0.024	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	0.016	0.020	. .	. .	. .	. .	. .	. .
. .	. .	0.018	0.012	. .	. .	. .	. .	. .	. .	. .	. .
. .	. .	0.021	0.023	. .	. .	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	. .	. .	. .	. .	0.006	0.019	. .	. .
. .	. .	. .	. .	. .	. .	. .	. .	0.014	0.014	. .	. .
0 012	0.007	. .	. .	. .	. .	. .	. .	. .	. .	0.012	0 009
0.015	0.009	. .	. .	. .	. .	. .	. .	. .	. .	0.014	0 012
0.014	0.011	. .	. .	. .	. .	. .	. .	. .	. .	0.013	0 014
. .	. .	. .	. .	. .	. .	. .	. .	0.013	0.010	. .	. .
. .	. .	. .	. .	. .	. .	. .	. .	0.015	0.010	. .	. .
. .	. .	. .	. .	0 016	0.025	. .	. .	. .	. .	. .	. .
. .	. .	. .	. .	0.013	0 018	. .	. .	. .	. .	. .	. .
. .	. .	0.012	0.012	. .	. .	. .	. .	. .	. .	. .	. .
. .	. .	0.012	0.016	. .	. .	. .	. .	. .	. .	. .	. .
. .	. .	0.007	0.014	. .	. .	. .	. .	. .	. .	. .	. .
0.015	0 017	0.018	0.021	0.017	0.020	0 019	0.021	0.018	0.017	0.015	0.017
Weighted means of all measurements										0.019	0.018
Weighted means at parallelism										0.021	0.020
Means as given by previous investigation under similar conditions										0.019	0.018

separate settings made by each of us agreed to within 45° on the head of one of the screws. This means that the grating can be set by plumb-line to within 3.3 minutes of arc.

Opening the slit and hanging the bob so that the thread could be seen through it, the various settings made by each of us agreed to 10° on a divided head fitted to the tangent screw. This means by calculation 1.7 minutes of arc of rotation of the slit.

On the other hand, using full length of slit, as in the previous case, and appropriate width, about 1/1000 inch, various exposures of the arc were taken on the same plate in the manner customary in making focus plates, except that the camera box was left clamped and the slit was oriented. Plates so taken showed no difference in the spectra when the scale on the divided head of the tangent screw was rotated 90° clockwise or counter clockwise from the position of parallelism as determined by plumb-line, making a change of 15.3 minutes in the orientation of the slit — a change nine times as great as that in the case of the plumb-line. However, the relative merits of the two methods must not be taken as nine to one, but merely as about four to one, for the plumb-line adjustment for the grating is only about one half as accurate as that for the slit.

The above facts make it extremely probable that the adjustment of the slit in the previous investigation was good. And, further, if with full length of slit no change in definition could be detected for a rotation of 90°, it is all the more probable that with a slit of 5 mm. length, as used in making regular exposures, the definition was the best obtainable.

(2) Further, as to *shift as a function of the orientation of the slit*, series of plates were taken with the slit oriented approximately 1° and 0.5° of arc clockwise and counter clockwise, including a series at parallelism; or 360° and 180° counter clockwise, 0°, 180°, and 360° clockwise on the divided head. If orientation introduce shift, the shift-orientation curve should either show a point of inflection at zero orientation or cross the displacement axis at that point. Table I, on pages 356 and 357, is self-explanatory. The data given in the table and the curves of Figure III show that for the two lines studied the shift is not influenced by the orientation of the slit.

The values of the shift obtained are, within the limits of error of experiment, the same as those obtained in the previous investigation.

The average deviation from the mean of two measurements (of the shift of a line) on any one plate is 0.003 (Kent) and 0.004 (Avery) t. m. for λ 3900.68; and 0.002 (Kent) and 0.003 (Avery) t. m. for λ 3913.58. It will be noticed that the value of the shift given on the

SHIFT-ORIENTATION CURVE FOR Ti. λλ 3900 AND 3913.

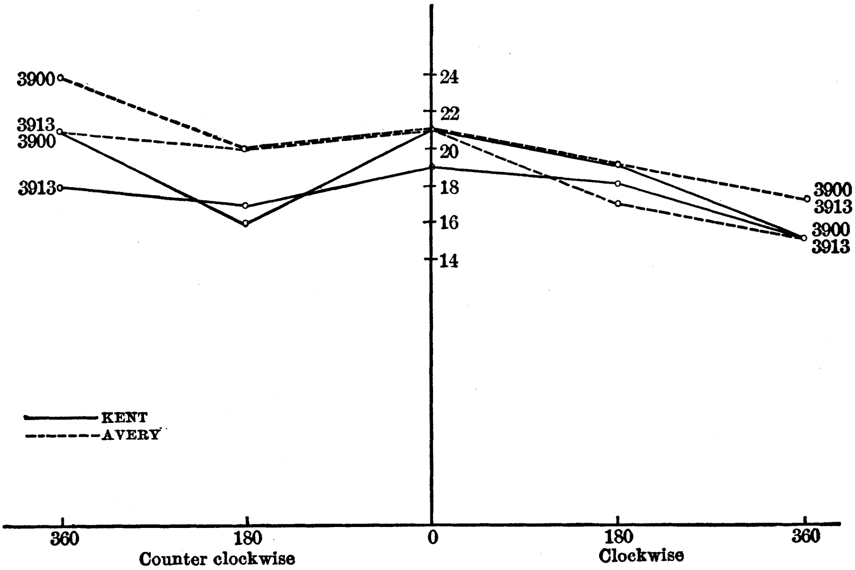

Figure 3.

Abscissas, Orientation in degrees. Ordinates, Shift in t. m. × 10^3.

TABLE II.

Arc and Arc.

Plate No.	Date.	λ 3900.68.				λ 3913.58.			
		Orientation of Slit.							
		Parallel, or 0°.		Counter clockwise 360°.		Parallel, or 0°.		Counter clockwise 360°.	
		Kent.	Avery.	Kent.	Avery.	Kent.	Avery.	Kent.	Avery.
106	April 27	–0.001	0.003	. .	. .	–0.002	0.002	. .	. .
107	"	0.001	0.002	. .	. .	0.004	0.003	. .	. .
109	"	. .	. .	0.002	0.005	. .	. .	0.003	0.002

different plates varies considerably. This is probably due to the fact that it was difficult to set the very end of the spark image accurately upon the slit. As shown in the previous paper, the part of the image employed influences the character of the line and the value of the shift.

During the progress of the work it was suggested to us that the use of the tip of the spark line as that part of the line upon which to set the thread of the microscope in measuring was perhaps objectionable owing to the fact that there might be a shift due to diffraction resulting from reducing the virtual aperture of the grating by strips of black paper set only *roughly* perpendicular to the ruling, the measurement being made by a mm. scale. Three exposures on one plate were therefore made, — all of the arc, and the first and third superimposed as usual. No shift was shown when the slit was either parallel or oriented, as indicated in the table on page 359.

At the end of the series of experiments the water rheostat was cut out of the transformer circuit, and in its place was inserted a choke coil of closed magnetic circuit of U form with adjustable armature. When adjusted roughly to show maximum power as measured by the wattmeter, with a spark-length as indicated in Table III, the shift was increased to 0.032 t. m. in the mean for λ 3900.68 and 0.033 t. m. for λ 3913.58.

TABLE III.

Conditions same as in Table I, except spark-length = 9 mm. in plate 125 and 15 mm. in plates 126 to 128. Time of exposures for spark = 60 seconds.

Plate No.	Date.	Conditions of Primary Circuit.			λ 3900.68.		λ 3913.58.	
					Orientation of Slit: Parallel, or 0°.			
		Amperes.	Watts.	Volts.	Kent.	Avery.	Kent.	Avery.
125	April 27	50	1000	28	0.040	0.038	0.031	0.040
126	"	49	950	27	0.033	0.033	0.030	0.049
127	"	50	800	24	0.030	0.030	0.032	0.029
128	"	50	800	26	0.026	0.029	0.022	0.031
Means					0.032	0.032	0.029	0.037

It is the purpose of the author of the former paper to study with an echelon the position of the narrow and less diffuse lines of the titanium spectrum.

In conclusion we wish to acknowledge the kindness shown us by Professor Trowbridge and those associated with him in so generously putting at our disposal all the facilities of the Jefferson Physical Laboratory; and our thanks are due also to the Rumford Committee for the grant made in aid of this research.

DEPARTMENT OF PHYSICS, BOSTON UNIVERSITY.
June, 1907.